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(54) **METHOD AND APPARATUS FOR PROVIDING ACKNOWLEDGEMENT BUNDLING**

(71) Applicant: **Nokia Solutions and Networks Oy**, Espoo (FI)

(72) Inventors: **Xiangguang Che**, Beijing (CN); **Peng Chen**, Beijing (CN); **Frank Frederiksen**, Klarup (DK); **Troels Kolding**, Klarup (DK)

(73) Assignee: **Nokia Solutions and Networks Oy**, Espoo (FI)

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H04W 72/12 (2009.01)
H04L 5/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H04L 5/0055*** (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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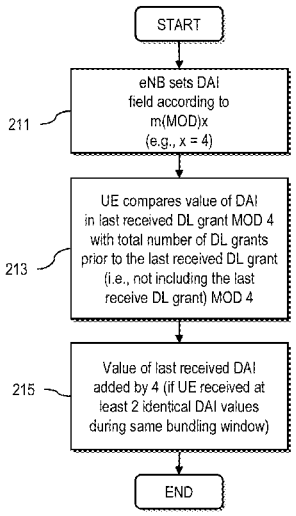
Primary Examiner — Chi H Pham
Assistant Examiner — Shick Hom
(74) *Attorney, Agent, or Firm* — Ditthavong & Steiner, P.C.

(57) **ABSTRACT**

An approach is provided for acknowledgement bundling. Dynamically scheduling of one or more of subframes per bundling window is performed by reusing an assignment index field (e.g., downlink assignment index (DAI) field). The assignment index field has a value greater than or equal to number of previously assigned subframes within the bundling window. The bundling window defines a group of subframes for common acknowledgement.

10 Claims, 12 Drawing Sheets



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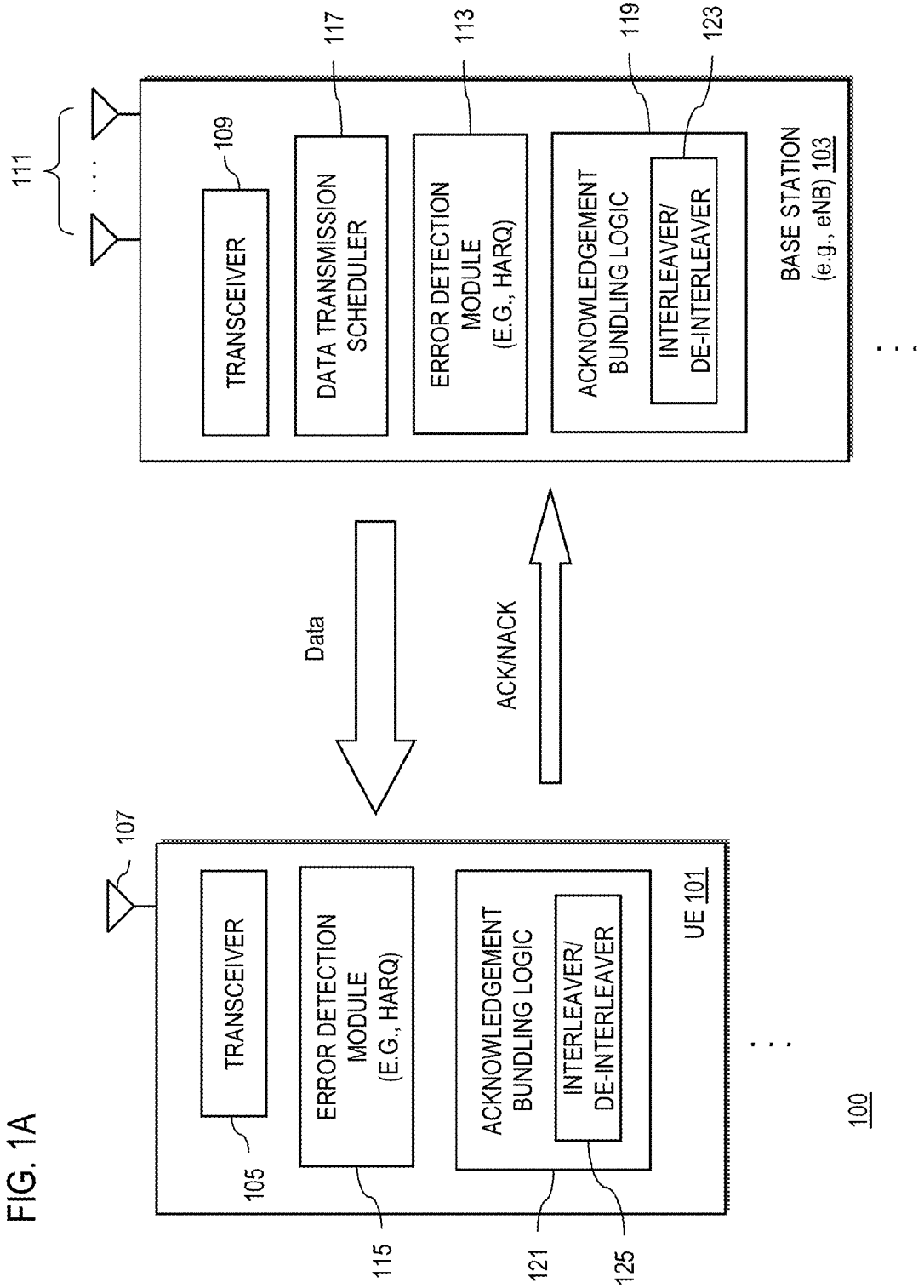

111
109
TRANSCEIVER
117
DATA TRANSMISSION SCHEDULER
113
ERROR DETECTION MODULE (E.G., HARQ)
119
ACKNOWLEDGEMENT BUNDLING LOGIC
123
INTERLEAVER/ DE-INTERLEAVER
BASE STATION (e.g., eNB) 103
Data
ACK/NACK
107
TRANSCEIVER
105
ERROR DETECTION MODULE (E.G., HARQ)
115
ACKNOWLEDGEMENT BUNDLING LOGIC
121
INTERLEAVER/ DE-INTERLEAVER
125
UE 101
100

FIG. 1A

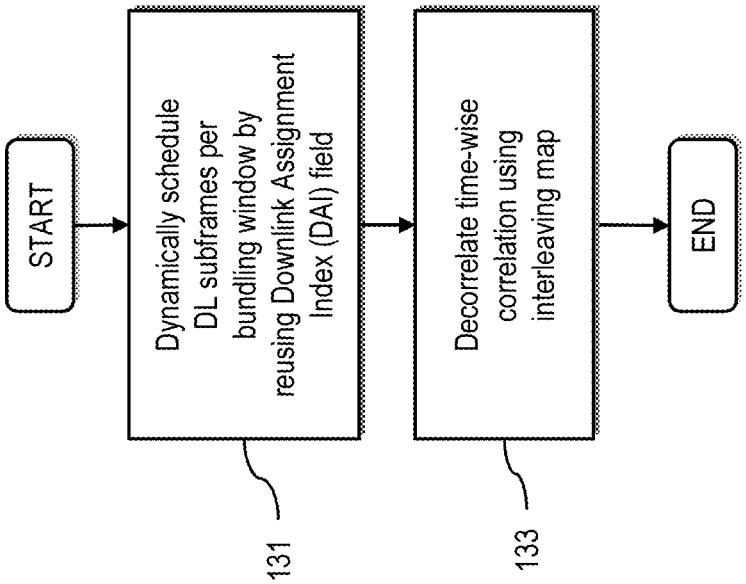

START
Dynamically schedule DL subframes per bundling window by reusing Downlink Assignment Index (DAI) field
Decorrelate time-wise correlation using interleaving map
END
131
133

FIG. 1B

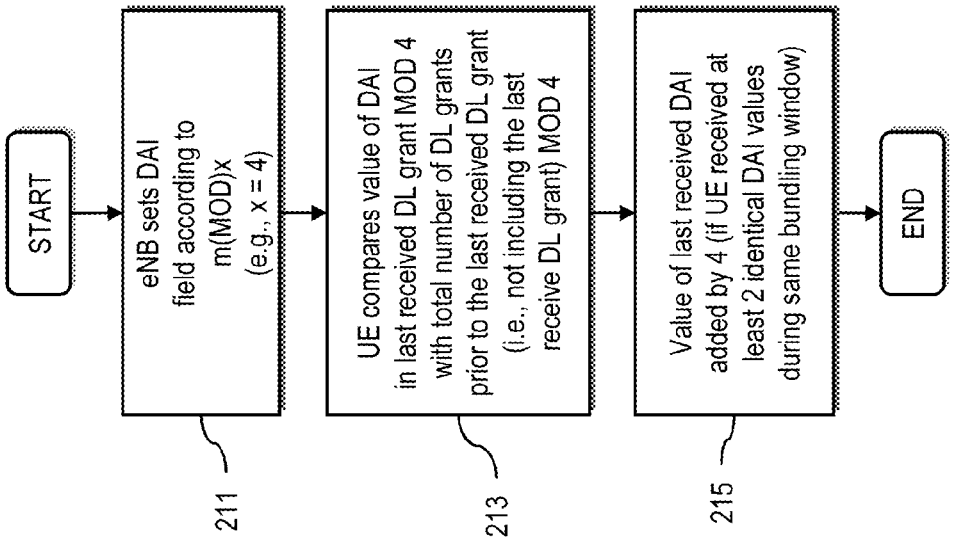

START
eNB sets DAI field according to m(MOD)x (e.g., x = 4)
UE compares value of DAI in last received DL grant MOD 4 with total number of DL grants prior to the last received DL grant (i.e., not including the last receive DL grant) MOD 4
Value of last received DAI added by 4 (if UE received at least 2 identical DAI values during same bundling window)
END
211
213
215

FIG. 2B

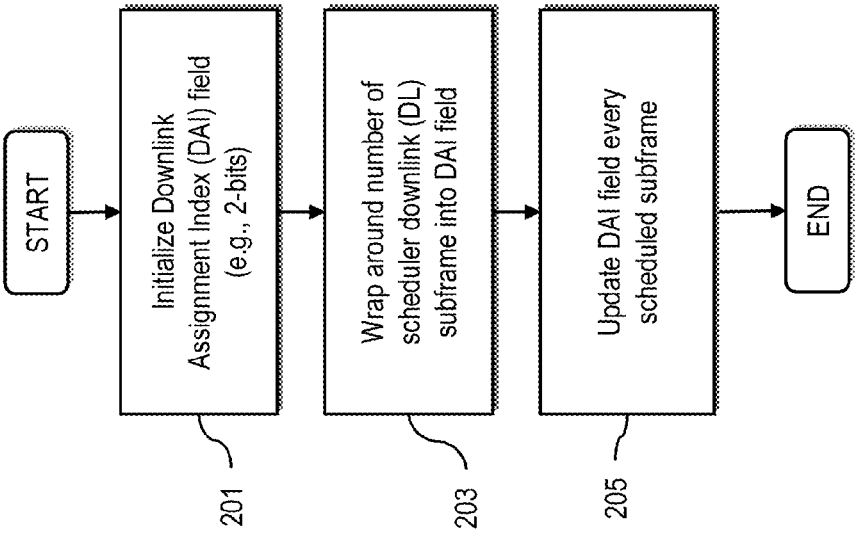

START
Initialize Downlink Assignment Index (DAI) field (e.g., 2-bits)
Wrap around number of scheduler downlink (DL) subframe into DAI field
Update DAI field every scheduled subframe
END
201
203
205

FIG. 2A

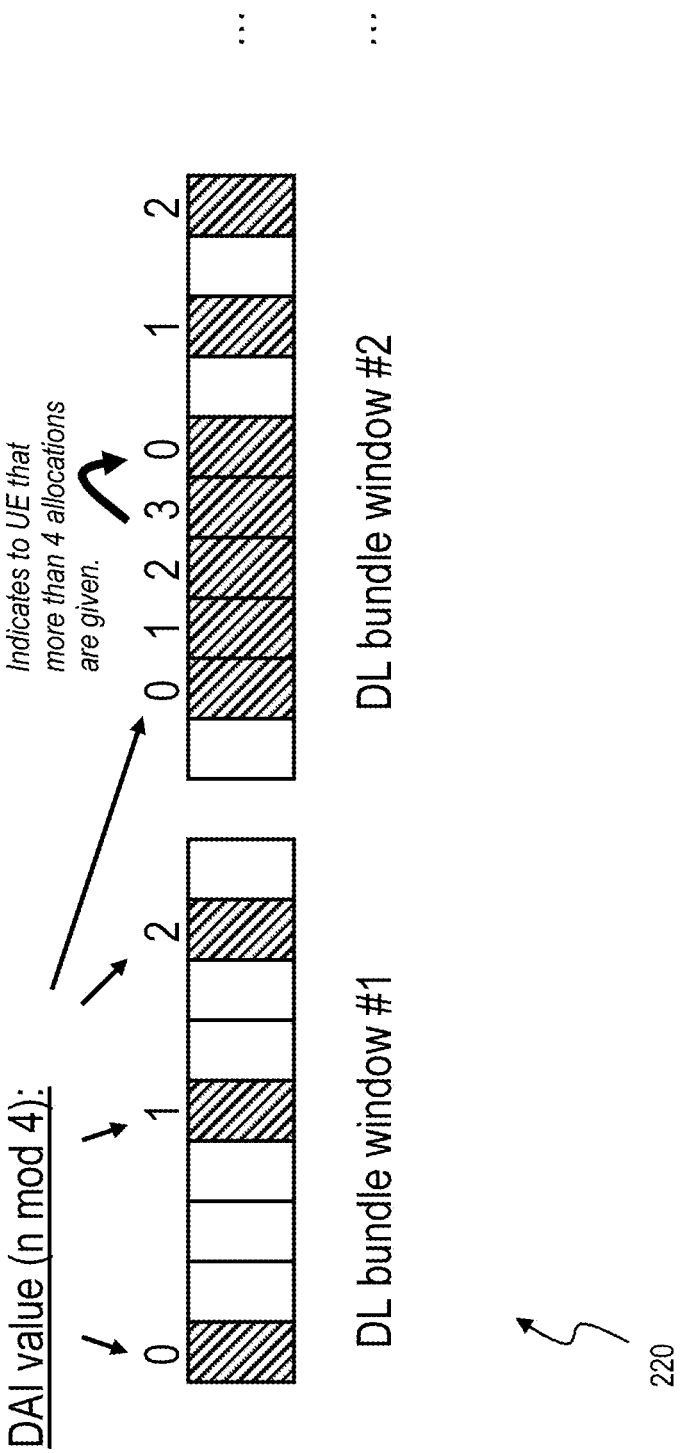

DAI value (n mod 4):
0
1
2
0
1
2
3
0
1
2
Indicates to UE that more than 4 allocations are given.
DL bundle window #1
DL bundle window #2
220

FIG. 2C

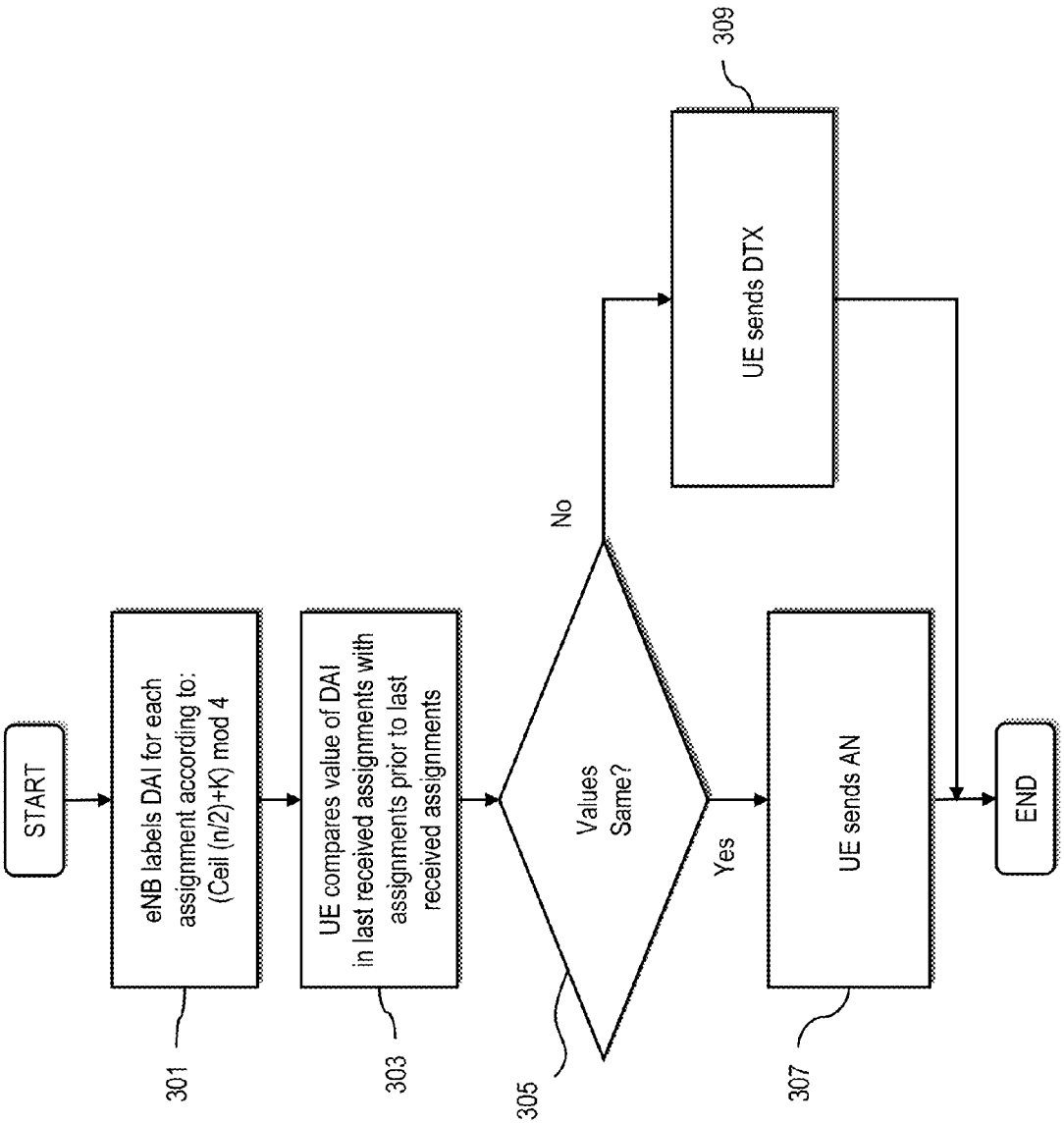
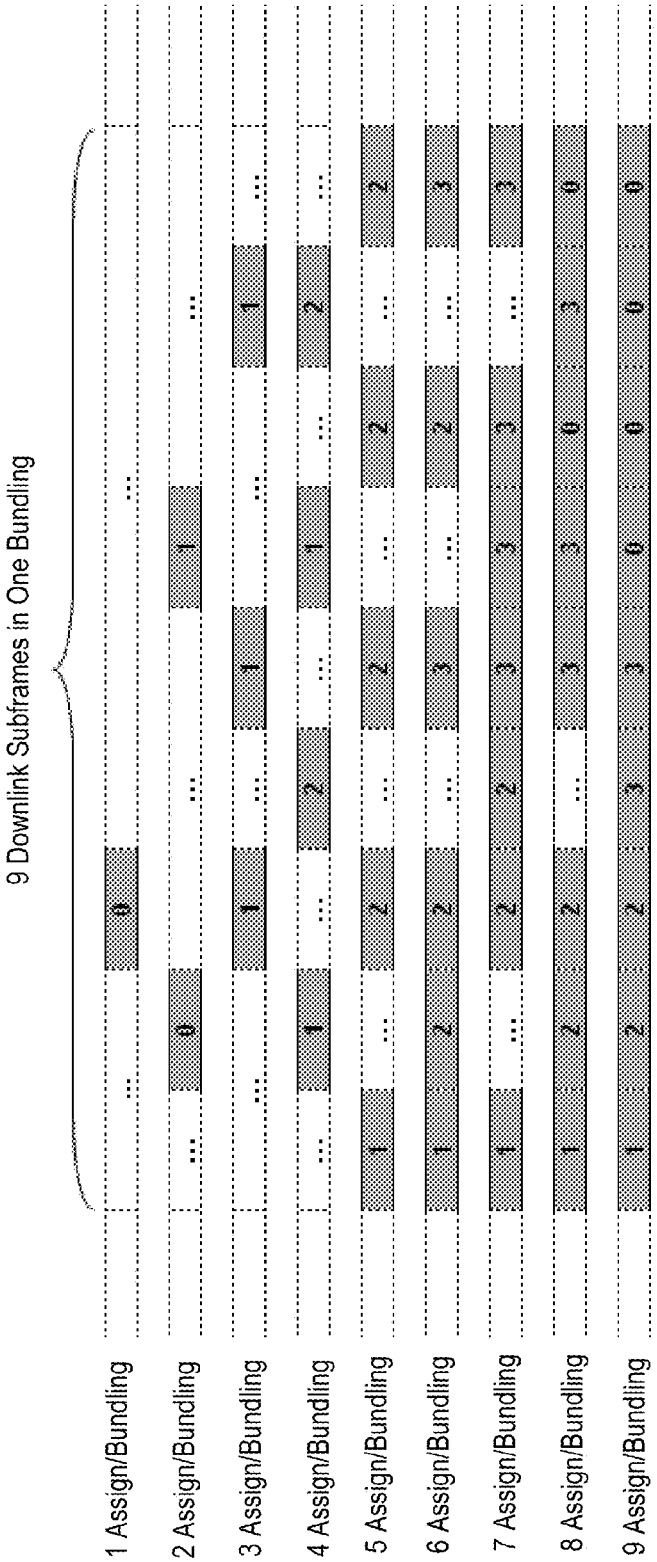

START
eNB labels DAI for each assignment according to: (Ceil (n/2)+K) mod 4
UE compares value of DAI in last received assignments with assignments prior to last received assignments
Values Same?
No
Yes
UE sends DTX
UE sends AN
END
301
303
305
307
309

FIG. 3A

FIG. 3B


9 Downlink Subframes in One Bundling
1 Assign/Bundling
2 Assign/Bundling
3 Assign/Bundling
4 Assign/Bundling
5 Assign/Bundling
6 Assign/Bundling
7 Assign/Bundling
8 Assign/Bundling
9 Assign/Bundling
320

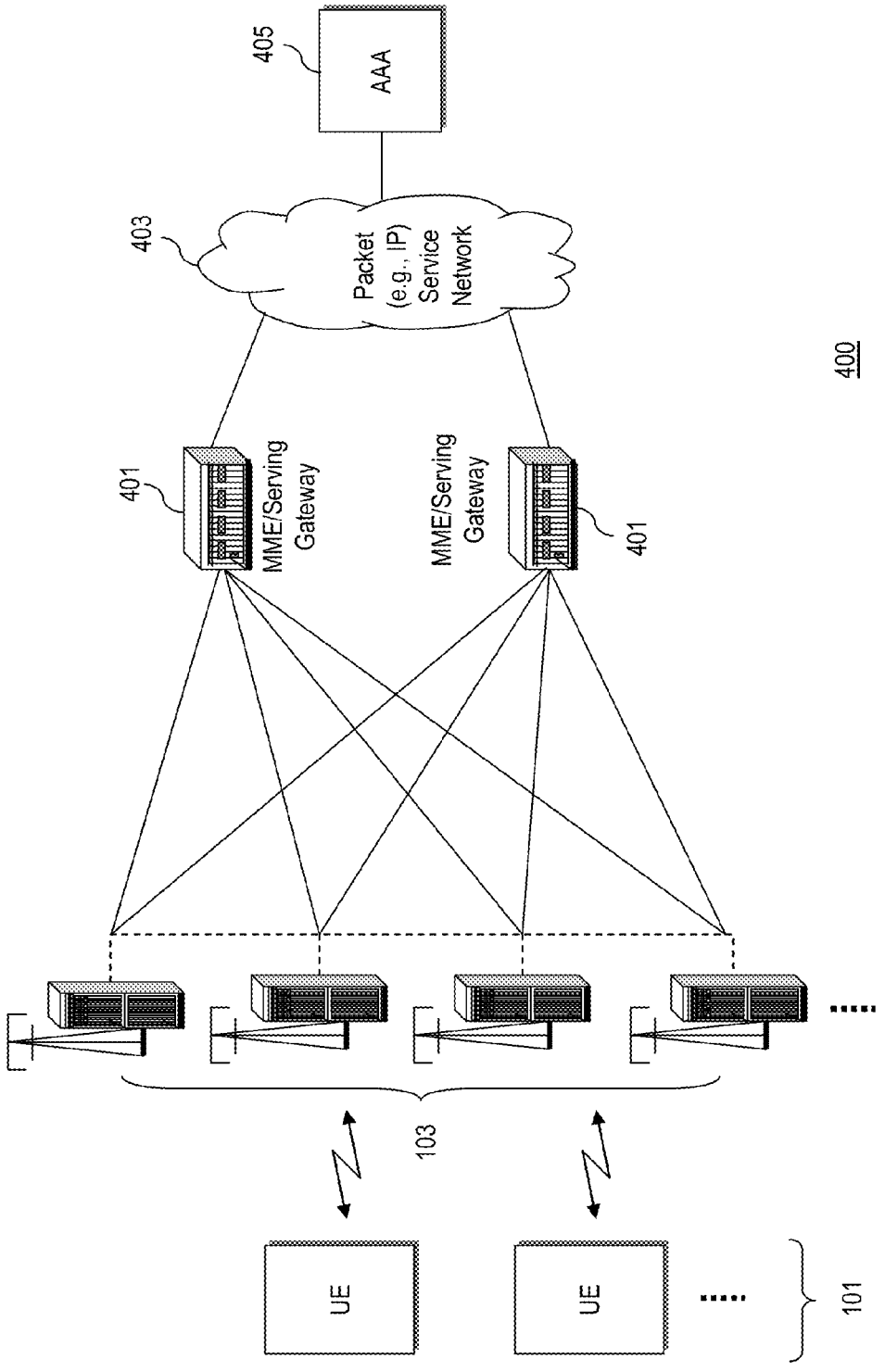

405
AAA
403
Packet (e.g., IP) Service Network
400
401
MME/Serving Gateway
MME/Serving Gateway
401
Base Station (e.g., E-UTRAN Node B (eNB))
103
UE
UE
101

FIG. 4A

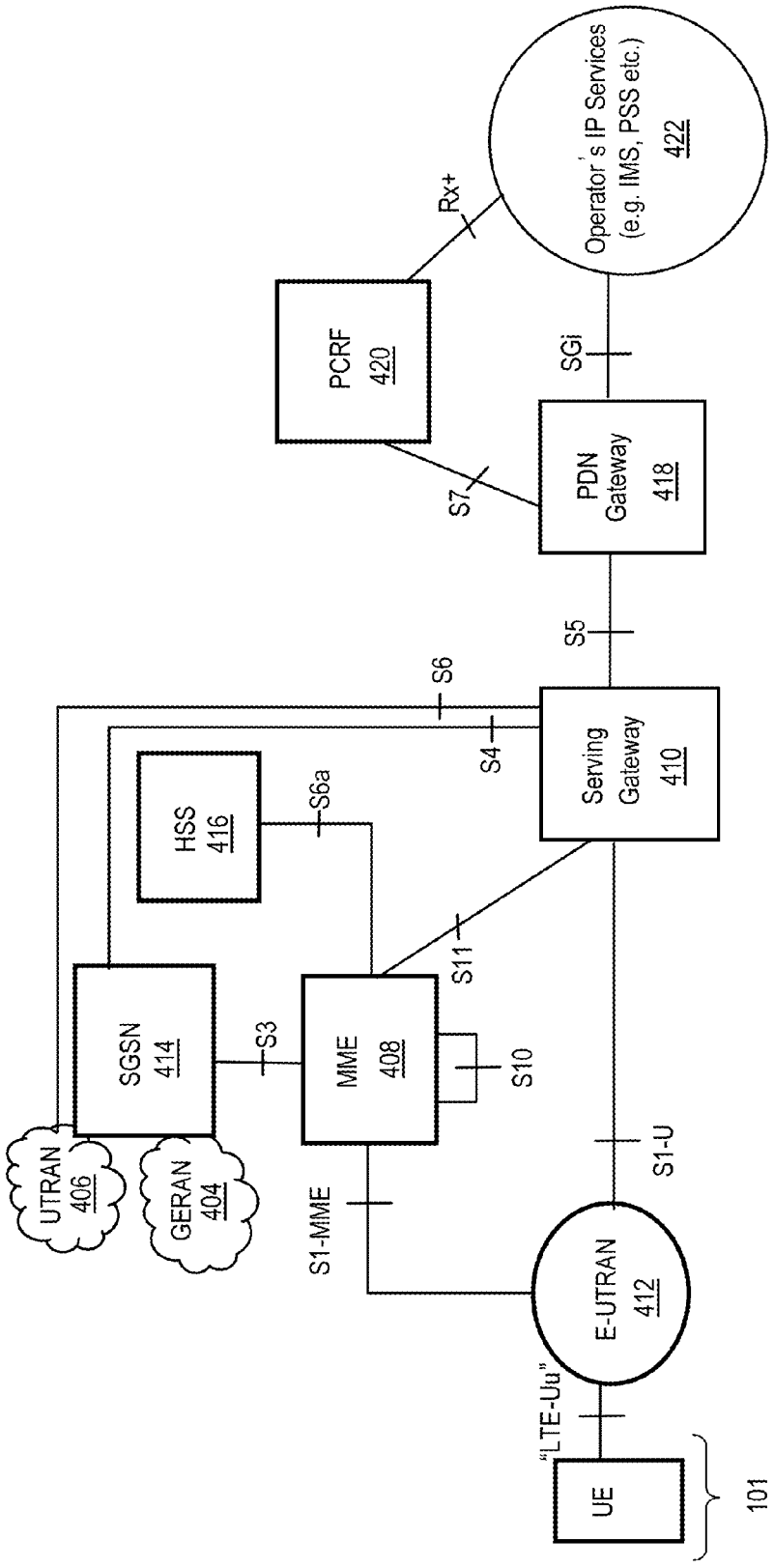

Operator's IP Services (e.g. IMS, PSS etc.) 422
Rx+
PCRF 420
SGi
S7
PDN Gateway 418
S5
S6
S4
Serving Gateway 410
HSS 416
S6a
S11
SGSN 414
S3
MME 408
S10
UTRAN 406
GERAN 404
S1-MME
S1-U
E-UTRAN 412
"LTE-Uu"
UE
101
402

FIG. 4B

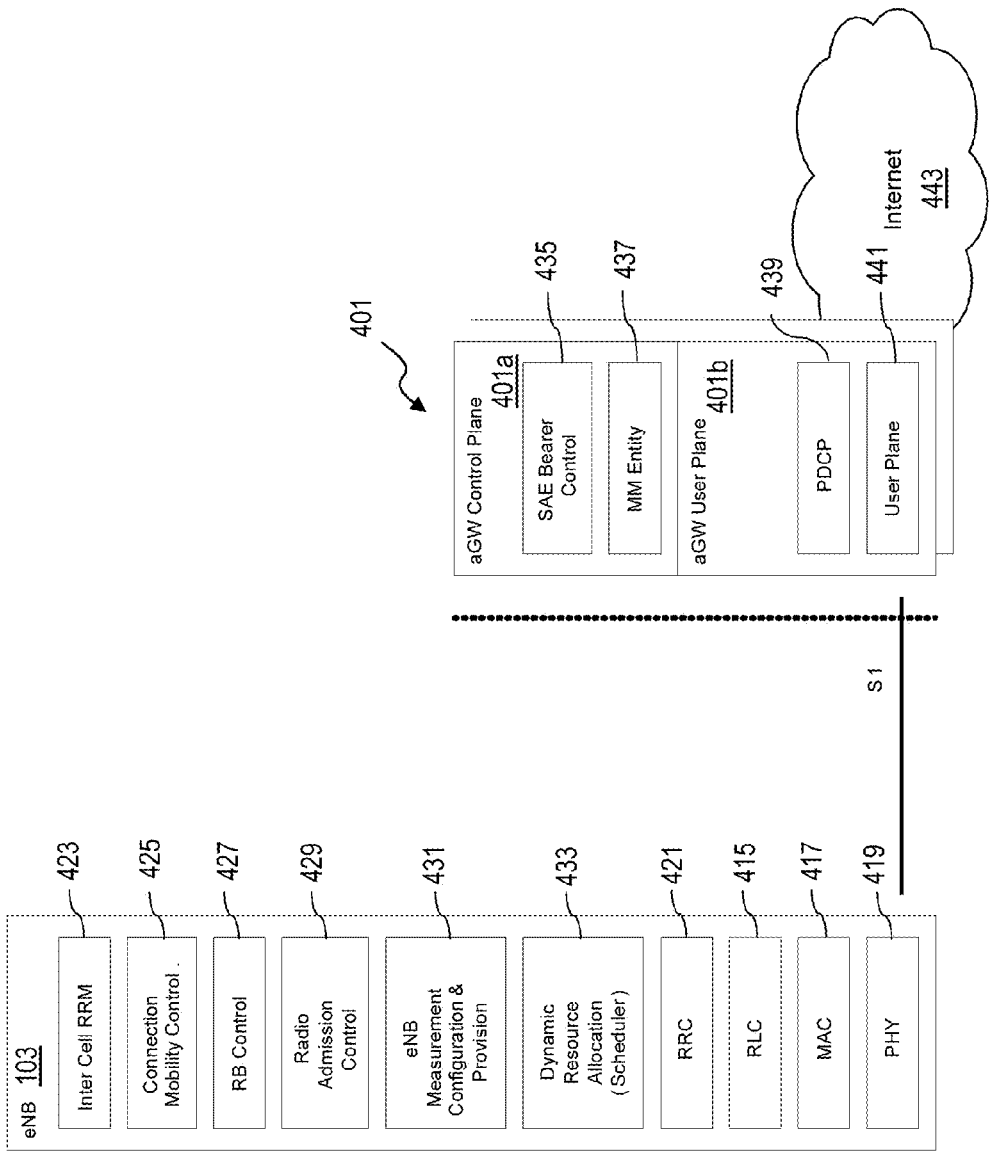

401
aGW Control Plane
401a
SAE Bearer Control
MM Entity
aGW User Plane
401b
PDCP
User Plane
Internet
443
435
437
439
441
S1
eNB 103
Inter Cell RRM
Connection Mobility Control
RB Control
Radio Admission Control
eNB Measurement Configuration & Provision
Dynamic Resource Allocation (Scheduler)
RRC
RLC
MAC
PHY
423
425
427
429
431
433
421
415
417
419

FIG. 4C

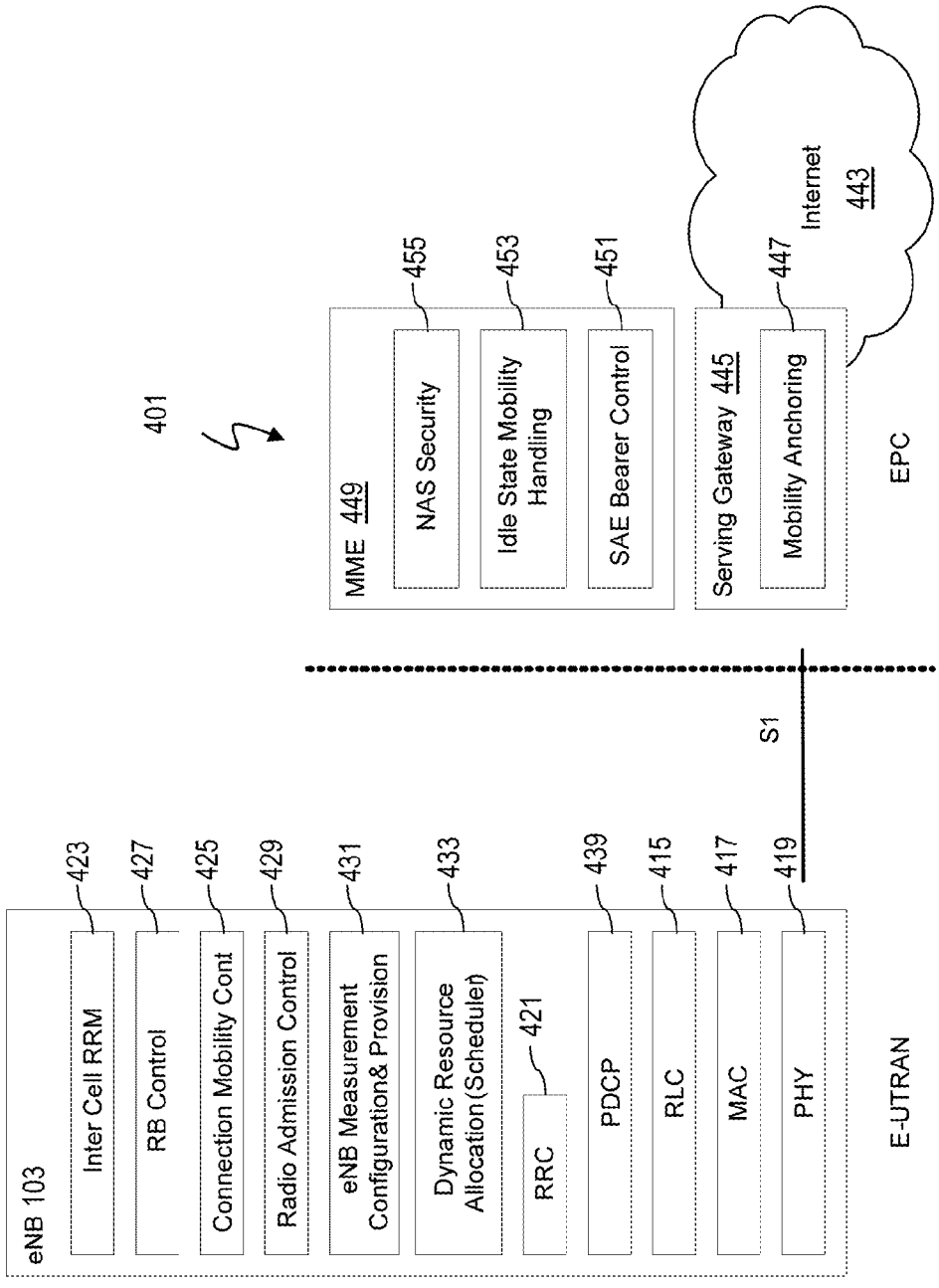

401
eNB 103
Inter Cell RRM
423
RB Control
427
Connection Mobility Cont
425
Radio Admission Control
429
eNB Measurement Configuration& Provision
431
Dynamic Resource Allocation (Scheduler)
433
RRC
421
PDCP
439
RLC
415
MAC
417
PHY
419
E-UTRAN
S1
MME 449
NAS Security
455
Idle State Mobility Handling
453
SAE Bearer Control
451
Serving Gateway 445
Mobility Anchoring
447
Internet
443
EPC

FIG. 4D

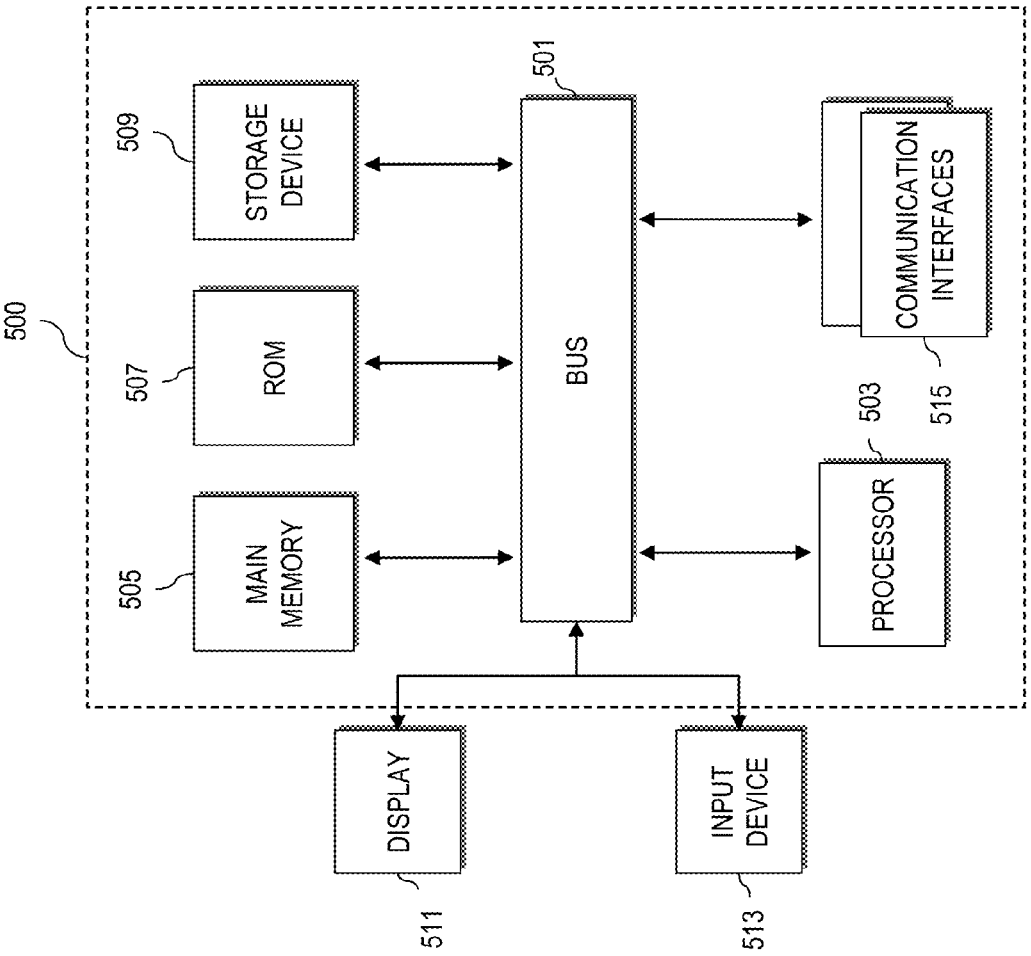

500
501
509
STORAGE DEVICE
507
ROM
505
MAIN MEMORY
BUS
COMMUNICATION INTERFACES
515
503
PROCESSOR
DISPLAY
511
INPUT DEVICE
513

FIG. 5

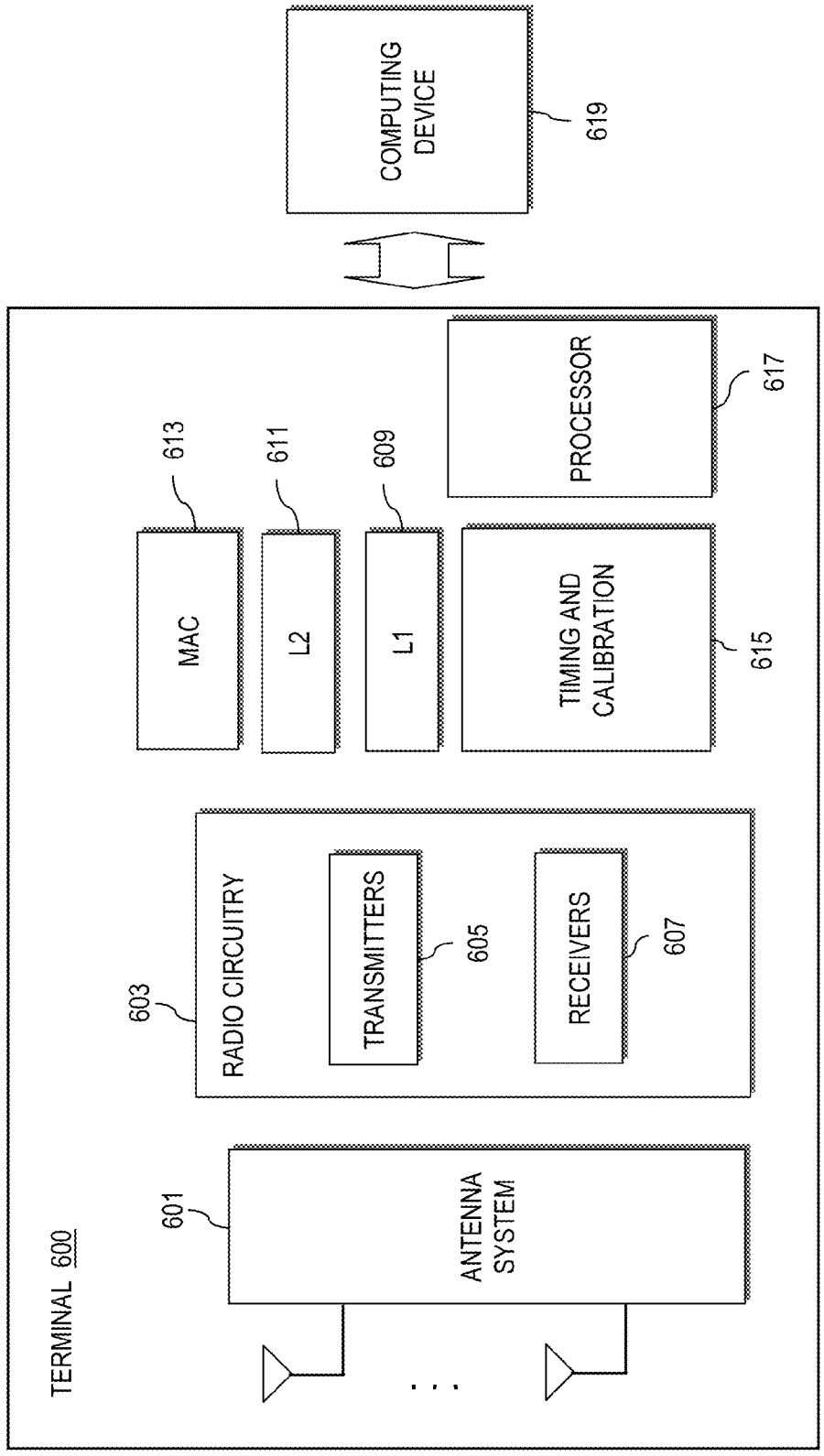

COMPUTING DEVICE
619
TERMINAL 600
601
ANTENNA SYSTEM
603
RADIO CIRCUITRY
TRANSMITTERS
605
RECEIVERS
607
MAC
613
L2
611
L1
609
TIMING AND CALIBRATION
615
PROCESSOR
617

FIG. 6

METHOD AND APPARATUS FOR PROVIDING ACKNOWLEDGEMENT BUNDLING

RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 12/489,988, filed Jun. 23, 2009, which claims the benefit of the earlier filing date under 35 U.S.C. §119(e) of U.S. Provisional Application Ser. No. 61/074,923 filed Jun. 23, 2008, entitled "Method and Apparatus for Providing Acknowledgement Bundling," the entireties of which are incorporated herein by reference.

BACKGROUND

Radio communication systems, such as a wireless data networks (e.g., Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) systems, spread spectrum systems (such as Code Division Multiple Access (CDMA) networks), Time Division Multiple Access (TDMA) networks, WiMAX (Worldwide Interoperability for Microwave Access), etc.), provide users with the convenience of mobility along with a rich set of services and features. This convenience has spawned significant adoption by an ever growing number of consumers as an accepted mode of communication for business and personal uses. To promote greater adoption, the telecommunication industry, from manufacturers to service providers, has agreed at great expense and effort to develop standards for communication protocols that underlie the various services and features. One area of effort involves acknowledgment signaling, whereby transmissions can be implicitly or explicitly acknowledged to convey successful transmission of data. An inefficient acknowledgement scheme can unnecessarily consume network resources.

Therefore, there is a need for an approach for providing efficient signaling, which can co-exist with already developed standards and protocols.

SOME EXEMPLARY EMBODIMENTS

According to certain exemplary embodiment, acknowledgement bundling can be provided for various communication link (e.g., uplink/downlink (UL/DL)) configurations by reusing a Downlink Assignment Index (DAI) field without increasing the length of DAI field.

According to one embodiment, a method comprises dynamically scheduling one or more of subframes per bundling window by reusing an assignment index field. The assignment index field has a value greater than or equal to number of previously assigned subframes within the bundling window. The bundling window defines a group of subframes for common acknowledgement.

According to another embodiment, an apparatus comprises logic configured to dynamically schedule one or more of subframes per bundling window by reusing an assignment index field. The assignment index field has a value greater than or equal to number of previously assigned subframes within the bundling window. The bundling window defines a group of subframes for common acknowledgement.

According to another embodiment, an apparatus comprises means for dynamically scheduling one or more of subframes per bundling window by reusing an assignment index field. The assignment index field has a value greater than or equal to number of previously assigned subframes within the bundling window. The bundling window defines a group of subframes for common acknowledgement.

According to another embodiment, a method comprises determining total number of resource grants. The method also comprises determining whether one or more resource grants have been missed by comparing a value of an assignment index field of a received bundling window with the total number of resource grants. The assignment index field is reused for dynamic scheduling of resources using a bundling window. The bundling window defines a group of subframes for common acknowledgement.

According to another embodiment, an apparatus comprises logic configured to logic configured to determine total number of resource grants and whether one or more resource grants have been missed by comparing a value of an assignment index field of a received bundling window with the total number of resource grants. The assignment index field is reused for dynamic scheduling of resources using a bundling window. The bundling window defines a group of subframes for common acknowledgement.

According to yet another embodiment, an apparatus comprises means for determining total number of resource grants. The method also comprises determining whether one or more resource grants have been missed by comparing a value of an assignment index field of a received bundling window with the total number of resource grants. The assignment index field is reused for dynamic scheduling of resources using a bundling window. The bundling window defines a group of subframes for common acknowledgement.

Still other aspects, features, and advantages of the invention are readily apparent from the following detailed description, simply by illustrating a number of particular embodiments and implementations, including the best mode contemplated for carrying out the invention. The invention is also capable of other and different embodiments, and its several details can be modified in various obvious respects, all without departing from the spirit and scope of the invention. Accordingly, the drawings and description are to be regarded as illustrative in nature, and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments of the invention are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings:

FIGS. **1**A and **1**B are, respectively, a diagram of a communication system capable of providing acknowledgement bundling, and a flowchart of the acknowledgement bundling process, according to an exemplary embodiment;

FIGS. **2**A-**2**C are, correspondingly, flowcharts of a process for reusing a downlink assignment index (DAI) field, and a diagram of exemplary downlink bundle windows, according to various exemplary embodiments;

FIGS. **3**A and **3**B are, respectively, a flowchart of a process for reusing a downlink assignment index (DAI) field, and a diagram of exemplary assignments within a bundle window, according to various exemplary embodiments;

FIGS. **4**A-**4**D are diagrams of communication systems having exemplary long-term evolution (LTE) and E-UTRA (Evolved Universal Terrestrial Radio Access) architectures, in which the system of FIG. **1** can operate to provide resource allocation, according to various exemplary embodiments of the invention;

FIG. **5** is a diagram of hardware that can be used to implement an embodiment of the invention; and

FIG. **6** is a diagram of exemplary components of a user terminal configured to operate in the systems of FIGS. **4**A-**4**D, according to an embodiment of the invention.

DESCRIPTION OF PREFERRED EMBODIMENT

An apparatus, method, and software for acknowledgement bundling are disclosed. In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the embodiments of the invention. It is apparent, however, to one skilled in the art that the embodiments of the invention may be practiced without these specific details or with an equivalent arrangement. In other instances, well-known structures and devices are shown in block diagram form in order to avoid unnecessarily obscuring the embodiments of the invention.

Although the embodiments of the invention are discussed with respect to a wireless network compliant with the Third Generation Partnership Project (3GPP) Long Term Evolution (LTE) architecture, it is recognized by one of ordinary skill in the art that the embodiments of the inventions have applicability to any type of communication system and equivalent functional capabilities.

FIGS. **1**A and **1**B are, respectively, a diagram of a communication system capable of providing acknowledgement bundling, and a flowchart of the acknowledgement bundling process, according to an exemplary embodiment. As shown in FIG. **1**A, system **100** includes one or more user equipment (UEs) **101** communicating with a base station **103**, which is part of an access network (not shown) (e.g., 3GPP LTE (or E-UTRAN, etc.). Under the 3GPP LTE architecture (as shown in FIGS. **4**A-**4**D), the base station **103** is denoted as an enhanced Node B (eNB). The system **100**, in certain embodiments, utilize an acknowledgement mechanism to provide accurate and timely exchange of information between the UE **101** and the eNB **103**. However, such acknowledgement signaling (i.e., using positive acknowledgements (ACKs) and/or negative acknowledgements (NACKs)) is overhead, and if not utilized properly can result in degraded network performance. To minimize signaling overhead, system **100** employs a scheme to bundle acknowledgement information. In one embodiment, dynamic scheduling of subframes per bundling window is implemented by reusing, for example, a downlink assignment index (DAI) field. Although the bundled acknowledgement scheme is explained with respect to the DAI field and downlink, it is contemplated that such scheme can be applied to other equivalent fields and communication link. As used herein, downlink refers to communication in the direction from the eNB **103** to the UE **101**, and uplink refers to communication from the UE **101** to the eNB **103**.

The UE **101** can be any type of mobile stations, such as handsets, terminals, stations, units, devices, multimedia tablets, Internet nodes, communicators, Personal Digital Assistants (PDAs) or any type of interface to the user (such as "wearable" circuitry, etc.). The UE **101** includes a transceiver **105** and an antenna system **107** that couples to the transceiver **105** to receive or transmit signals from the base station **103**. The antenna system **107** can include one or more antennas. For the purposes of illustration, the time division duplex (TDD) mode of 3GPP is described herein; however, it is recognized that other modes can be supported, e.g., frequency division duplex (FDD).

As with the UE **101**, the base station **103** employs a transceiver **109**, which transmits information to the UE **101**. Also, the base station **103** can employ one or more antennas **111** for transmitting and receiving electromagnetic signals. For instance, the Node B **103** may utilize a Multiple Input Multiple Output (MIMO) antenna system **111**, whereby the Node B **103** can support multiple antenna transmit and receive capabilities. This arrangement can support the parallel transmission of independent data streams to achieve high data rates between the UE **101** and Node B **103**. The base station **103**, in an exemplary embodiment, uses OFDM (Orthogonal Frequency Divisional Multiplexing) as a downlink (DL) transmission scheme and a single-carrier transmission (e.g., SC-FDMA (Single Carrier-Frequency Division Multiple Access) with cyclic prefix for the uplink (UL) transmission scheme. SC-FDMA can also be realized using a DFT-S-OFDM principle, which is detailed in 3GGP TR 25.814, entitled "Physical Layer Aspects for Evolved UTRA," v.1.5.0, May 2006 (which is incorporated herein by reference in its entirety). SC-FDMA, also referred to as Multi-User-SC-FDMA, allows multiple users to transmit simultaneously on different sub-bands.

In one embodiment, the system of FIG. **1**A provides MBMS (Multimedia Broadcast Multicast Services) services in a MBSFN (Multimedia Broadcast Single Frequency Network). An MBSFN typically has other neighboring MBSFNs or unicast networks operating at the same frequency.

Communications between the UE **101** and the base station **103** (and thus, the network) is governed, in part, by control information exchanged between the two entities. Such control information, in an exemplary embodiment, is transported over a control channel on, for example, the downlink from the base station **103** to the UE **101**.

By way of example, a number of communication channels are defined for use in the system **100**. The channel types include: physical channels, transport channels, and logical channels. Physical channels can include a physical downlink shared channel (PDSCH), a dedicated physical downlink dedicated channel (DPDCH), a dedicated physical control channel (DPCCH), etc. Additional, a Physical Uplink Control Channel (PUCCH) is provided. The transport channels can be defined by how they transfer data over the radio interface and the characteristics of the data. The transport channels include a broadcast channel (BCH), paging channel (PCH), a dedicated shared channel (DSCH), etc. Other exemplary transport channels are an uplink (UL) Random Access Channel (RACH), Common Packet Channel (CPCH), Forward Access Channel (FACH), Downlink Shared Channel (DLSCH), Uplink Shared Channel (USCH), Broadcast Channel (BCH), and Paging Channel (PCH). A dedicated transport channel is the UL/DL Dedicated Channel (DCH). Each transport channel is mapped to one or more physical channels according to its physical characteristics.

Each logical channel can be defined by the type and required Quality of Service (QoS) of information that it carries. The associated logical channels include, for example, a broadcast control channel (BCCH), a paging control channel (PCCH), Dedicated Control Channel (DCCH), Common Control Channel (CCCH), Shared Channel Control Channel (SHCCH), Dedicated Traffic Channel (DTCH), Common Traffic Channel (CTCH), etc.

The BCCH (Broadcast Control Channel) can be mapped onto both BCH and DSCH. As such, this is mapped to the PDSCH; the time-frequency resource can be dynamically allocated by using L1/L2 control channel (PDCCH). In this case, BCCH (Broadcast Control Channel)-RNTI (Radio Network Temporary Identities) is used to identify the resource allocation information.

As noted, to ensure accurate delivery of information between the eNB **103** and the UE **101**, the system **100** utilizes error detection to exchange information, e.g., Hybrid ARQ (HARQ). HARQ is a concatenation of Forward Error Correction (FEC) coding and an Automatic Repeat Request (ARQ) protocol. Automatic Repeat Request (ARQ) is an error detection mechanism used on the link layer. As such, this error detection scheme, as well as other schemes (e.g., CRC (cyclic

redundancy check)), can be performed by error detection modules **113** and **115** within the eNB **103** and UE **101**, respectively. The HARQ mechanism permits the receiver (e.g., UE **101**) to indicate to the transmitter (e.g., eNB **103**) that a packet or sub-packet has been received incorrectly, and thus, requests the transmitter to resend the particular packet (s).

According to one embodiment, downlink hybrid-ARQ acknowledgements in TDD can be transmitted as a single ACK/NACK feedback where ACK/NACKs from one or several DL subframes are combined ("bundled" by performing AND operation of all A/N) to a single ACK/NACK report and the Physical Uplink Control Channel (PUCCH) formats already defined for LTE are reused (PUCCH Format 1a/1b). This ACK/NACK mode is referred to as "AN-bundling." For example, with respect to AN bundling for UL/DL configurations (except configuration 5), one implementation is to employ a Downlink Assignment Index (DAI) field (e.g. 2-bit), which is added to DCI formats 1, 1A, 1B, and 2. For example, ACK or NACK feedback can be provided from scheduled DL subframes in which the DAI value of a prior assignment can be compared with a latest assignment to determine any missed assignments.

In certain embodiments, the downlink assignment index must be greater than or equal to the number of previously assigned subframes within the bundling window and must be less or equal to the maximum number of dynamic assignments within the bundling window. The UE **101** can use the CCE index in last received/detected dynamic DL assignment as well as the subframe number to (i) check for missed DL assignments and (ii) determine the UL ACK/NACK PUCCH index. Further, it is assumed that semi-persistent assignments are not counted in the downlink assignment index.

It is recognized that the DAI field is constrained, for example, by 2-bits; however, there are up to 9 DL subframes during one bundling window which can be dynamically scheduled. Thus 2-bits cannot fully cover 1-9 DL subframes per bundling window.

To better appreciate the bundling approach of certain embodiments, it is instructive to describe the following three conventional mechanisms: options 1-3.

In option 1, the two DAI bits indicate if it is the only, first, last, or neither first nor last dynamically assigned DL subframe within the bundling window. The UE can assume that the assigned subframes are consecutive. The drawback of this option is that it enforces only consecutive time domain scheduling, which is greatly limiting the packet scheduler's flexibility in the packet oriented wireless access system. Thus, performance is degraded, and complexity is increased. Furthermore, this is in contradiction with the scheme agreed for other UL/DL configurations.

With option 2, partial sub-frame bundling and ACK/NACK multiplexing scheme is used. The 9 DL sub-frames (including DwPTS) are assigned to X (X>1) bundling windows. For each bundling window, at most 8 ACK/NACK bits can be bundled together regardless of whether it is single codeword or not. ACK/NACK multiplexing scheme is used to transmit multiple ACK/NACK bits corresponding to each bundling window. A drawback of this approach is that it is not a true AN-bundling scheme, but is a multi-bits scheme—which means that it does not provide an AN-bundling solution for 9DL:1UL configuration.

With option 3, an eNB can dynamically schedule at most 4 downlink subframes to a UE within the bundling window. Remaining downlink resources (if they exist) can be covered by semi-persistent or multi-cast assignment. MBSFN subframes can further reduce the unicast downlink subframes in a bundling window. The drawback is that scheduler cannot fully exploit the performance gain from dynamic scheduling for all 9 DL subframes. Also, it is expected that performance degradation is incurred with semi-persistent scheduling due to limited/none frequency selective gain and low efficiency of resource utilization because resources are pre-allocated for each users and can be re-allocated only every rather long time, e.g., a few seconds or even longer.

As shown in FIG. **1**B, the approach of system **100** permits a scheduler **117** full flexibility to dynamically, as in step **131**, schedule any of the, e.g., 9 DL subframes per bundling window by reusing the agreed 2-bits DAI for other UL/DL configurations (i.e., not increase the length of DAI). Additionally, from the UE **101** perspective, such mechanism should be simple to adopt. Further, interleaving is employed to decorrelate time-wise correlations associated with the bundling mechanism (step **133**). This process, in an exemplary embodiment, is performed by the eNB **103** in conjunction with the UE **101** using corresponding acknowledgement bundling logic **119**, **121**. Further, each of the acknowledgement bundling logic **119**, **121** can employ an interleaver/deinterleaver **123**, **125**.

Two approaches are provided: Method 1 and Method 2, as shown respectively in FIGS. **2**A-**2**C and **3**A and **3**B. Under Method 1 (detailed in FIGS. **2**A-**2**C), wrap-around the number of scheduler DL subframe into 2-bits DAI, and this value is updated every scheduled subframe. With Method 2 (detailed in FIGS. **3**A and **3**B), the process uses (Ceil (Counter/2)+K) modulo 4, where K is a boolean value to indicate whether at least 2 subframes will be dynamically assigned in the subframes within the bundling window. In other words, if there are 0 or 1 subframes that will be dynamic assigned in the following subframes within the bundling window, K=0; otherwise, K=1. Counter is the number of scheduler DL subframes and is updated every subframe.

According to certain embodiments, these processes can incorporate an interleaving method, which introduces a time-wise decorrelation of the consecutive PDCCHs received. When interleaving, the interleaver map will break the regular pattern of the potential correlated PDCCH errors.

FIGS. **2**A-**2**C are, correspondingly, flowcharts of a process for reusing a downlink assignment index (DAI) field, and a diagram of exemplary downlink bundle windows, according to various exemplary embodiments. In this embodiment of Method 1 (as shown in FIG. **2**A), a simple extension from the DAI definition can be made for other UL/DL configurations. In step **201**, the process initializes the DAI field. Next, the number of scheduler downlink (DL) subframe is wrapped around into the DAI field, as in step **203**. A counter 'm' is utilized to count the number of scheduled DL subframe; and 'm' is updated in each subframe. That is, the DAI field is updated in every scheduled subframe, as in step **205**.

Thus, from the eNB side (as seen in FIG. **2**B), in step **211**, the DAI field is set according to m (modulo)×(where m and x are integers); for example, m MOD 4. From the UE side, the UE **101** will compare, per step **213**, the value of DAI in the last received DL grant MOD 4 with the total received number of DL grant prior to the last received DL grant (i.e. not including the last receive DL grant) MOD 4 during the bundling window to detect whether some grant(s) have been missed, and AN or DTX (data transmission) will be sent, if the comparison is equal or non-equal, respectively. If UE **101** has received at least 2 of the same (identical) DAI values during the same bundling window, the value of the last received DAI should be added '4' (step **215**).

FIG. **2**C shows an example of DL bundle windows **220**, in which bundle window #**1** specifies DAI values corresponding

to subframes **1**, **5**, and **8**. That is, 3 assignments are provided. Bundle window #**2** provides DAI values corresponding to subframes **2**-**6**, **7**, and **9**; i.e., 6 assignments.

The above process, according to certain embodiments, provides a relatively simple method for accommodating other UL/DL configuration, and can readily to be added on top the AN bundling for all other configurations (from both standards and implementation point of view). Additionally, there is no restriction imposed on the scheduler **117**.

It is noted that a DTX->ACK problem may occur if UE missed **4** consecutive DL grants, for instance. Although the probability of such case is rather low in practice, the eNB **103** can "fall-back" to the conventional option-3 (as explained earlier) freely and dynamically to completely avoid such error case if the eNB **103** foresees that this error may occur and the performance loss is "unacceptable". That is, this approach provides for "free & dynamic switch" between Method-1 and Option-3.

FIGS. **3**A and **3**B are, respectively, a flowchart of a process for reusing a downlink assignment index (DAI) field, and a diagram of exemplary assignments within a bundle window, according to various exemplary embodiments. In this embodiment, the eNB **103** labels, as in step **301**, DAI for each assignment as follows: (Ceil (n/2)+K) mod 4, where n is the number of previous scheduled assignments within the bundling window, and K (as previously stated) is a boolean value to indicate 0/1 subframe (K=0) or at least 2 subframes (K=1) will be scheduled in following subframes within the bundling window.

In step **303**, the UE **101** compares two values: sum_DAI_2 last received assignments mod 4 and number_of_assignments_before_last_received assignment mod 4. If two values are the same (as determined in step **305**), the UE **101** will send AN (step **307**). Otherwise, the UE **101** sends DTX, per step **309**.

FIG. **3**B shows an example of the various assignments **320** within a single bundle. In this example, 9 downlink subframes can provided within one bundle.

The above process, according to certain embodiments, imposes no restriction on the scheduler **117**. Also, there is no error case or false error probability. It is noted that the eNB **103** has to "pre-estimate" the scheduling decision at least 2 subframe ahead. This, if compared with conventional option-3, is less restrictive requirement since semi-persistent scheduling for 5 subframes actually mean that eNB **103** should do "pre-estimate" the scheduling decision much longer than 2 subframe ahead.

As mentioned an interleaving process can be employed with the processes of FIGS. **2**A-**2**C and **3**A and **3**B. Specifically, an interleaver map provides decorrelation of time-wise correlations. In one example, a block interleaver with 5 columns and 2 rows can be utilized (e.g., for interleavers **123**, **125**). When inserting the data into the interleaver **125**, data is written row-by-row, while the output is read column-by-column. To ensure maximum decorrelation, the first element of the interleaver matrix is filled with a "dummy" value, which is ignored when reading from the matrix. The reason for this being that typically for this TDD configuration there are 9 PDCCHs that are to be transmitted. Essentially, using this interleaver map, the sequence: {1,2,3,4,5,6,7,8,9} can be mapped into the sequence {5,1,6,2,7,3,8,4,9}, where it is seen that the distance between consecutive PDCCH "counters" will be 4 or 5 depending on the time of observation. It is noted that introducing such an interleaver element yields the need to perform scheduling decisions 5 subframes ahead (since the DAI signaling value of subframe **5** needs to be transmitted in subframe **1** due to the interleaver). With time-wise decorrelation, the false-positive probability will become lower. It is noted that with the use of interleaving, there may be a need for a pre-estimation of up to 5 subframes, thereby requiring some scheduling ahead (the exact value in subframe **5** needs signaling, so the decisions in subframes **1**-**4** are also needed).

In certain embodiments, the processes described above can be performed within an UMTS terrestrial radio access network (UTRAN) or Evolved UTRAN (E-UTRAN) in 3GPP, as next described.

FIGS. **4**A-**4**D are diagrams of communication systems having exemplary long-term evolution (LTE) architectures, in which the user equipment (UE) and the base station of FIG. **1**A can operate, according to various exemplary embodiments of the invention. By way of example (shown in FIG. **4**A), a base station (e.g., destination node) and a user equipment (UE) (e.g., source node) can communicate in system **400** using any access scheme, such as Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Wideband Code Division Multiple Access (WCDMA), Orthogonal Frequency Division Multiple Access (OFDMA) or Single Carrier Frequency Division Multiple Access (FDMA) (SC-FDMA) or a combination of thereof. In an exemplary embodiment, both uplink and downlink can utilize WCDMA. In another exemplary embodiment, uplink utilizes SC-FDMA, while downlink utilizes OFDMA.

The communication system **400** is compliant with 3GPP LTE, entitled "Long Term Evolution of the 3GPP Radio Technology" (which is incorporated herein by reference in its entirety). As shown in FIG. **4**A, one or more user equipment (UEs) communicate with a network equipment, such as a base station **103**, which is part of an access network (e.g., WiMAX (Worldwide Interoperability for Microwave Access), 3GPP LTE (or E-UTRAN), etc.). Under the 3GPP LTE architecture, base station **103** is denoted as an enhanced Node B (eNB).

MME (Mobile Management Entity)/Serving Gateways **401** are connected to the eNBs **103** in a full or partial mesh configuration using tunneling over a packet transport network (e.g., Internet Protocol (IP) network) **403**. Exemplary functions of the MME/Serving GW **401** include distribution of paging messages to the eNBs **103**, termination of U-plane packets for paging reasons, and switching of U-plane for support of UE mobility. Since the GWs **401** serve as a gateway to external networks, e.g., the Internet or private networks **403**, the GWs **401** include an Access, Authorization and Accounting system (AAA) **405** to securely determine the identity and privileges of a user and to track each user's activities. Namely, the MME Serving Gateway **401** is the key control-node for the LTE access-network and is responsible for idle mode UE tracking and paging procedure including retransmissions. Also, the MME **401** is involved in the bearer activation/deactivation process and is responsible for selecting the SGW (Serving Gateway) for a UE at the initial attach and at time of intra-LTE handover involving Core Network (CN) node relocation.

A more detailed description of the LTE interface is provided in 3GPP TR 25.813, entitled "E-UTRA and E-UTRAN: Radio Interface Protocol Aspects," which is incorporated herein by reference in its entirety.

In FIG. **4**B, a communication system **402** supports GERAN (GSM/EDGE radio access) **404**, and UTRAN **406** based access networks, E-UTRAN **412** and non-3GPP (not shown) based access networks, and is more fully described in TR 23.882, which is incorporated herein by reference in its entirety. A key feature of this system is the separation of the network entity that performs control-plane functionality (MME **408**) from the network entity that performs bearer-plane functionality (Serving Gateway **410**) with a well

defined open interface between them S11. Since E-UTRAN **412** provides higher bandwidths to enable new services as well as to improve existing ones, separation of MME **408** from Serving Gateway **410** implies that Serving Gateway **410** can be based on a platform optimized for signaling transactions. This scheme enables selection of more cost-effective platforms for, as well as independent scaling of, each of these two elements. Service providers can also select optimized topological locations of Serving Gateways **410** within the network independent of the locations of MMEs **408** in order to reduce optimized bandwidth latencies and avoid concentrated points of failure.

As seen in FIG. **4**B, the E-UTRAN (e.g., eNB) **412** interfaces with UE **101** via LTE-Uu. The E-UTRAN **412** supports LTE air interface and includes functions for radio resource control (RRC) functionality corresponding to the control plane MME **408**. The E-UTRAN **412** also performs a variety of functions including radio resource management, admission control, scheduling, enforcement of negotiated uplink (UL) QoS (Quality of Service), cell information broadcast, ciphering/deciphering of user, compression/decompression of downlink and uplink user plane packet headers and Packet Data Convergence Protocol (PDCP).

The MME **408**, as a key control node, is responsible for managing mobility UE identifies and security parameters and paging procedure including retransmissions. The MME **408** is involved in the bearer activation/deactivation process and is also responsible for choosing Serving Gateway **410** for the UE **101**. MME **408** functions include Non Access Stratum (NAS) signaling and related security. MME **408** checks the authorization of the UE **101** to camp on the service provider's Public Land Mobile Network (PLMN) and enforces UE **101** roaming restrictions. The MME **408** also provides the control plane function for mobility between LTE and 2G/3G access networks with the S3 interface terminating at the MME **408** from the SGSN (Serving GPRS Support Node) **414**.

The SGSN **414** is responsible for the delivery of data packets from and to the mobile stations within its geographical service area. Its tasks include packet routing and transfer, mobility management, logical link management, and authentication and charging functions. The S6a interface enables transfer of subscription and authentication data for authenticating/authorizing user access to the evolved system (AAA interface) between MME **408** and HSS (Home Subscriber Server) **416**. The S10 interface between MMEs **408** provides MME relocation and MME **408** to MME **408** information transfer. The Serving Gateway **410** is the node that terminates the interface towards the E-UTRAN **412** via S1-U.

The S1-U interface provides a per bearer user plane tunneling between the E-UTRAN **412** and Serving Gateway **410**. It contains support for path switching during handover between eNBs **43**. The S4 interface provides the user plane with related control and mobility support between SGSN **414** and the 3GPP Anchor function of Serving Gateway **410**.

The S12 is an interface between UTRAN **406** and Serving Gateway **410**. Packet Data Network (PDN) Gateway **418** provides connectivity to the UE **101** to external packet data networks by being the point of exit and entry of traffic for the UE **101**. The PDN Gateway **418** performs policy enforcement, packet filtering for each user, charging support, lawful interception and packet screening. Another role of the PDN Gateway **418** is to act as the anchor for mobility between 3GPP and non-3GPP technologies such as WiMax and 3GPP2 (CDMA 1X and EvDO (Evolution Data Only)).

The S7 interface provides transfer of QoS policy and charging rules from PCRF (Policy and Charging Role Function) **420** to Policy and Charging Enforcement Function (PCEF) in the PDN Gateway **418**. The SGi interface is the interface between the PDN Gateway and the operator's IP services including packet data network **422**. Packet data network **422** may be an operator external public or private packet data network or an intra operator packet data network, e.g., for provision of IMS (IP Multimedia Subsystem) services. Rx+ is the interface between the PCRF and the packet data network **422**.

As seen in FIG. **4**C, the eNB **43** utilizes an E-UTRA (Evolved Universal Terrestrial Radio Access) (user plane, e.g., RLC (Radio Link Control) **415**, MAC (Media Access Control) **417**, and PHY (Physical) **419**, as well as a control plane (e.g., RRC **421**)). The eNB **43** also includes the following functions: Inter Cell RRM (Radio Resource Management) **423**, Connection Mobility Control **425**, RB (Radio Bearer) Control **427**, Radio Admission Control **429**, eNB Measurement Configuration and Provision **431**, and Dynamic Resource Allocation (Scheduler) **433**.

The eNB **43** communicates with the aGW **401** (Access Gateway) via an S1 interface. The aGW **401** includes a User Plane **401***a* and a Control plane **401***b*. The control plane **401***b* provides the following components: SAE (System Architecture Evolution) Bearer Control **435** and MM (Mobile Management) Entity **437**. The user plane **401***b* includes a PDCP (Packet Data Convergence Protocol) **439** and a user plane functions **441**. It is noted that the functionality of the aGW **401** can also be provided by a combination of a serving gateway (SGW) and a packet data network (PDN) GW. The aGW **401** can also interface with a packet network, such as the Internet **443**.

In an alternative embodiment, as shown in FIG. **4**D, the PDCP (Packet Data Convergence Protocol) functionality can reside in the eNB **43** rather than the GW **401**. Other than this PDCP capability, the eNB functions of FIG. **4**C are also provided in this architecture.

In the system of FIG. **4**D, a functional split between E-UTRAN and EPC (Evolved Packet Core) is provided. In this example, radio protocol architecture of E-UTRAN is provided for the user plane and the control plane. A more detailed description of the architecture is provided in 3GPP TS 86.300.

The eNB **43** interfaces via the S1 to the Serving Gateway **445**, which includes a Mobility Anchoring function **447**. According to this architecture, the MME (Mobility Management Entity) **449** provides SAE (System Architecture Evolution) Bearer Control **451**, Idle State Mobility Handling 453, and NAS (Non-Access Stratum) Security **455**.

One of ordinary skill in the art would recognize that the processes for acknowledgement bundling may be implemented via software, hardware (e.g., general processor, Digital Signal Processing (DSP) chip, an Application Specific Integrated Circuit (ASIC), Field Programmable Gate Arrays (FPGAs), etc.), firmware, or a combination thereof. Such exemplary hardware for performing the described functions is detailed below.

FIG. **5** illustrates exemplary hardware upon which various embodiments of the invention can be implemented. A computing system **500** includes a bus **501** or other communication mechanism for communicating information and a processor **503** coupled to the bus **501** for processing information. The computing system **500** also includes main memory **505**, such as a random access memory (RAM) or other dynamic storage device, coupled to the bus **501** for storing information and instructions to be executed by the processor **503**. Main memory **505** can also be used for storing temporary variables or other intermediate information during execution of instructions by the processor **503**. The computing system **500**

may further include a read only memory (ROM) **507** or other static storage device coupled to the bus **501** for storing static information and instructions for the processor **503**. A storage device **509**, such as a magnetic disk or optical disk, is coupled to the bus **501** for persistently storing information and instructions.

The computing system **500** may be coupled via the bus **501** to a display **511**, such as a liquid crystal display, or active matrix display, for displaying information to a user. An input device **513**, such as a keyboard including alphanumeric and other keys, may be coupled to the bus **501** for communicating information and command selections to the processor **503**. The input device **513** can include a cursor control, such as a mouse, a trackball, or cursor direction keys, for communicating direction information and command selections to the processor **503** and for controlling cursor movement on the display **511**.

According to various embodiments of the invention, the processes described herein can be provided by the computing system **500** in response to the processor **503** executing an arrangement of instructions contained in main memory **505**. Such instructions can be read into main memory **505** from another computer-readable medium, such as the storage device **509**. Execution of the arrangement of instructions contained in main memory **505** causes the processor **503** to perform the process steps described herein. One or more processors in a multi-processing arrangement may also be employed to execute the instructions contained in main memory **505**. In alternative embodiments, hard-wired circuitry may be used in place of or in combination with software instructions to implement the embodiment of the invention. In another example, reconfigurable hardware such as Field Programmable Gate Arrays (FPGAs) can be used, in which the functionality and connection topology of its logic gates are customizable at run-time, typically by programming memory look up tables. Thus, embodiments of the invention are not limited to any specific combination of hardware circuitry and software.

The computing system **500** also includes at least one communication interface **515** coupled to bus **501**. The communication interface **515** provides a two-way data communication coupling to a network link (not shown). The communication interface **515** sends and receives electrical, electromagnetic, or optical signals that carry digital data streams representing various types of information. Further, the communication interface **515** can include peripheral interface devices, such as a Universal Serial Bus (USB) interface, a PCMCIA (Personal Computer Memory Card International Association) interface, etc.

The processor **503** may execute the transmitted code while being received and/or store the code in the storage device **509**, or other non-volatile storage for later execution. In this manner, the computing system **500** may obtain application code in the form of a carrier wave.

The term "computer-readable medium" as used herein refers to any medium that participates in providing instructions to the processor **503** for execution. Such a medium may take many forms, including but not limited to non-volatile media, volatile media, and transmission media. Non-volatile media include, for example, optical or magnetic disks, such as the storage device **509**. Volatile media include dynamic memory, such as main memory **505**. Transmission media include coaxial cables, copper wire and fiber optics, including the wires that comprise the bus **501**. Transmission media can also take the form of acoustic, optical, or electromagnetic waves, such as those generated during radio frequency (RF) and infrared (IR) data communications. Common forms of computer-readable media include, for example, a floppy disk, a flexible disk, hard disk, magnetic tape, any other magnetic medium, a CD-ROM, CDRW, DVD, any other optical medium, punch cards, paper tape, optical mark sheets, any other physical medium with patterns of holes or other optically recognizable indicia, a RAM, a PROM, and EPROM, a FLASH-EPROM, any other memory chip or cartridge, a carrier wave, or any other medium from which a computer can read.

Various forms of computer-readable media may be involved in providing instructions to a processor for execution. For example, the instructions for carrying out at least part of the invention may initially be borne on a magnetic disk of a remote computer. In such a scenario, the remote computer loads the instructions into main memory and sends the instructions over a telephone line using a modem. A modem of a local system receives the data on the telephone line and uses an infrared transmitter to convert the data to an infrared signal and transmit the infrared signal to a portable computing device, such as a personal digital assistant (PDA) or a laptop. An infrared detector on the portable computing device receives the information and instructions borne by the infrared signal and places the data on a bus. The bus conveys the data to main memory, from which a processor retrieves and executes the instructions. The instructions received by main memory can optionally be stored on storage device either before or after execution by processor.

FIG. **6** is a diagram of exemplary components of a user terminal configured to operate in the systems of FIGS. **4**A-**4**D, according to an embodiment of the invention. A user terminal **600** includes an antenna system **601** (which can utilize multiple antennas) to receive and transmit signals. The antenna system **601** is coupled to radio circuitry **603**, which includes multiple transmitters **605** and receivers **607**. The radio circuitry encompasses all of the Radio Frequency (RF) circuitry as well as base-band processing circuitry. As shown, layer-1 (L1) and layer-2 (L2) processing are provided by units **609** and **611**, respectively. Optionally, layer-3 functions can be provided (not shown). Module **613** executes all Medium Access Control (MAC) layer functions. A timing and calibration module **615** maintains proper timing by interfacing, for example, an external timing reference (not shown). Additionally, a processor **617** is included. Under this scenario, the user terminal **600** communicates with a computing device **619**, which can be a personal computer, work station, a Personal Digital Assistant (PDA), web appliance, cellular phone, etc.

While the invention has been described in connection with a number of embodiments and implementations, the invention is not so limited but covers various obvious modifications and equivalent arrangements, which fall within the purview of the appended claims. Although features of the invention are expressed in certain combinations among the claims, it is contemplated that these features can be arranged in any combination and order.

What is claimed is:

1. A method comprising:

dynamically scheduling one or more of subframes per bundling window by reusing an assignment index field, wherein the assignment index field has a value greater than or equal to number of previously assigned subframes within the bundling window, the bundling window defining a group of subframes for common acknowledgement;

setting the assignment index field according to m modulo x, wherein m and x are integers;

comparing a value of the assignment index field associated with a last received downlink grant modulo x with a total

number of downlink grants prior to the last received downlink grant modulo x; and

adding the value of the assignment index field associated with the last received downlink by x, if there are at least two identical assignment index field values in the bundling window, x being an integer.

2. The method according to claim **1**, further comprising:

labeling the assignment index field for each assignment according to (Ceil (n/2)+K) modulo x, wherein n and x are integers, and K is a boolean value to indicate whether at least 2 subframes will be dynamic assigned in the subframes within the bundling window.

3. The method according to claim **2**, wherein the assignment index field is a downlink assignment index field, and x equals 4.

4. The method according to claim **2**, wherein a value of the assignment index field associated with a last received downlink grant is compared with a total number of downlink grants.

5. The method according to claim **4**, wherein a predetermined number of downlink grants have been missed, and the dynamic scheduling is performed according to a maximum number of subframes associated with the bundling window.

6. An apparatus comprising:

at least one processor; and

at least one memory including computer program code,

the at least one memory and the computer program code configured to, with the at least one processor, cause the apparatus to perform at least the following:

dynamically schedule one or more of subframes per bundling window by reusing an assignment index field, wherein the assignment index field has a value greater than or equal to number of previously assigned subframes within the bundling window, the bundling window defining a group of subframes for common acknowledgement,

set the assignment index field according to m modulo x, m and x being integers,

compare a value of the assignment index field associated with a last received downlink grant modulo x with a total number of downlink grants prior to the last received downlink grant modulo x, and

add the value of the assignment index field associated with the last received downlink by x, if there are at least two identical assignment index field values in the bundling window, x being an integer.

7. The apparatus according to claim **6**, wherein the apparatus is further caused to:

label the assignment index field for each assignment according to (Ceil (n/2)+K) modulo x, wherein n and x are integers, and K is a boolean value to indicate whether at least 2 subframes will be dynamic assigned in the subframes within the bundling window.

8. The apparatus according to claim **7**, wherein the assignment index field is a downlink assignment index field, and x equals 4.

9. The apparatus according to claim **7**, wherein a value of the assignment index field associated with a last received downlink grant is compared with a total number of downlink grants.

10. The apparatus according to claim **9**, wherein a predetermined number of downlink grants have been missed, and the apparatus is further caused to:

dynamically schedule according to a maximum number of subframes associated with the bundling window.

* * * * *